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HEAT FLOW STUDIES, COSO GEOTHERMAL AREA, CHINA LAKE, CALIFORNIA

TECHNICAL REPORT # 3
FEBRUARY 28, 1973

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CONTENTS

Summary 1

Future Plans 2

Progress For Reporting Period 3

Heat Flow Studies 3

Seismic Studies 12

References 14

Appendix I 15

Appendix II 23

Figures:

1. Location Map of the Coso Geothermal Area 4

2. Heat Flow Borehole UTD-Coso #10 5

3. Temperature-Depth Curves for the *UTD-Coso* Heat Flow Boreholes 6

4. Base Map With Preliminary Heat Flow Values 11

5. Base Map of Seismograph Sites and Epicenters 13

I-1. Temperature Depth-Curve for Borehole UTD-Coso #1 16

I-2. Temperature Depth-Curve for Borehole UTD-Coso #2 17

I-3. Temperature Depth-Curve for Borehole UTD-Coso #5 18

I-4. Temperature Depth-Curve for Borehole UTD-Coso #6 19

I-5. Temperature Depth-Curve for Borehole UTD-Coso #7 20

I-6. Temperature Depth-Curve for Borehole UTD-Coso #8 21

I-7. Temperature Depth-Curve for Borehole UTD-Coso #10 22

Tables:

1. Heat Flow Data for UTD-Coso #6 Heat Flow Borehole 8

2. Coso Geothermal Area Preliminary Heat Flow Data 10

FUTURE PLANS

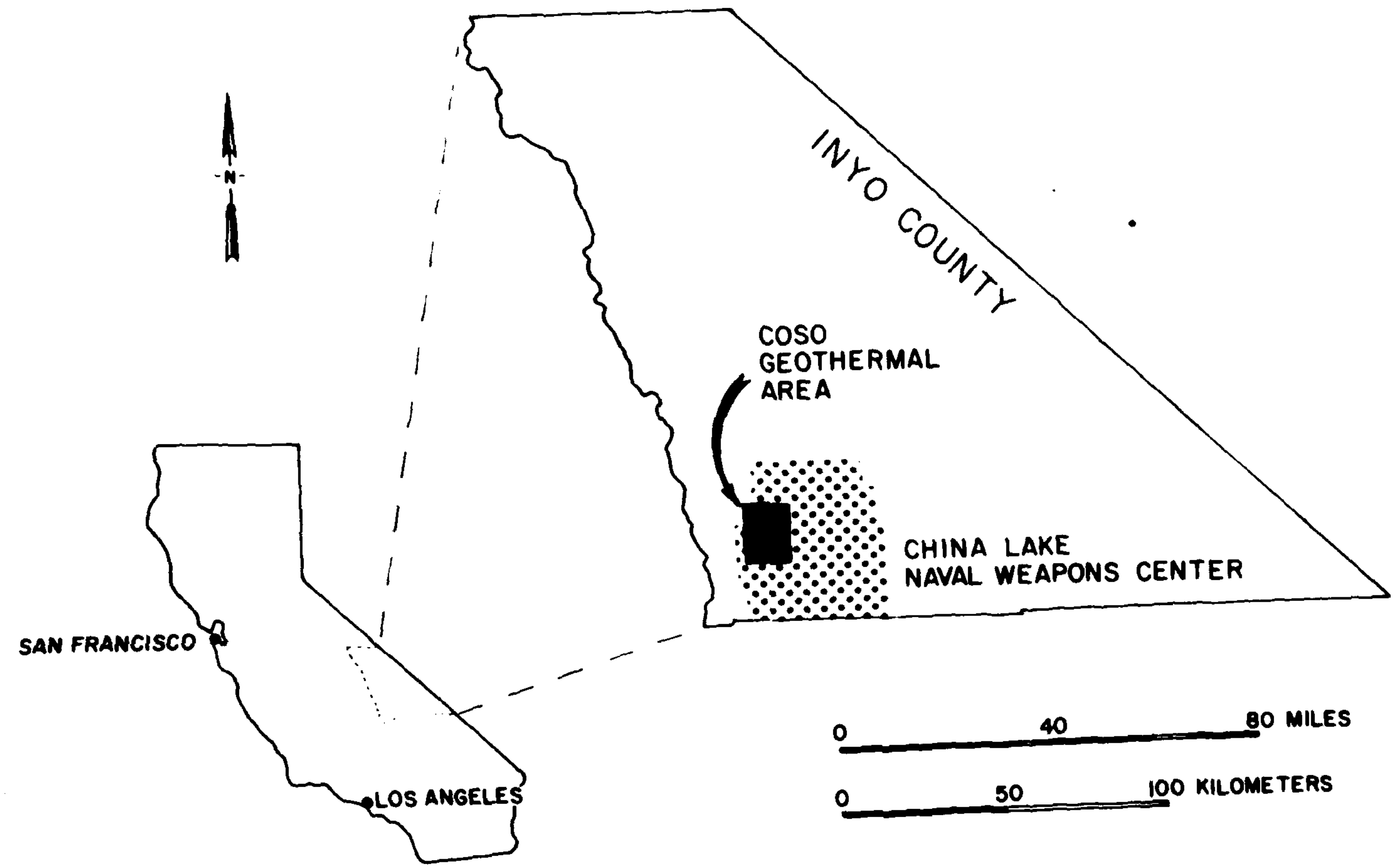
During the final quarter, thermal conductivity measurements will be completed on all of the drill cuttings as well as the core samples. These thermal conductivity values will be combined with the calculated geothermal gradients to obtain heat flow determinations for the seven boreholes, providing useful temperature information. Unpublished heat flow data from the region will be obtained from investigators at the United States Geological Survey. Examination and interpretation of the microearthquake events will be continued. The seismic and heat flow data collected in the Coso Geothermal Area will be compared to, and integrated with, other geological, geochemical, and geophysical observations in order to synthesize the available information and formulate a conceptual model of the Coso geothermal system.

PROGRESS FOR REPORTING PERIOD

Heat Flow Studies

Heat flow studies in the Coso Geothermal Area (Fig. 1), China Lake, California, were continued during the third quarter of the present study. Temperature measurements were completed in nine of the heat flow boreholes. The tenth hole, UTD-Coso #4, was only seven meters deep and therefore no temperature measurements were made. A 5.1 cm diameter PVC pipe was placed in eight of the heat flow holes and drill cuttings were caved around the pipe (Fig. 2). A 5.1 cm diameter steel pipe was lowered into UTD-Coso #2 because of the high temperatures (over 40°C) measured in the drilling mud. A 7 meter section of metal casing was emplaced in UTD-Coso #4.

Temperatures were measured at five meter intervals from the ground surface to the deepest five meter interval. Subsequently, temperatures were remeasured two or three times in each borehole in order to demonstrate that equilibrium thermal conditions existed. The maximum difference in temperature, at any of the five meter intervals, was 0.03 °C. Temperature-depth curves for seven of the boreholes are presented in Figure 3. Temperature-depth curves were not plotted for three of the boreholes, UTD-Coso #3, #4, and #9, since none of these holes penetrated deeper than 15 meters. Results from these boreholes, as well as from the other seven, indicate that the temperature data above 15 meters is useless for calculating the geothermal gradient. This is due to the effects of solar radiation at the surface of the earth. Separate temperature-depth curves for each of the holes are presented in Appendix I. Temperatures, as a function of depth at five meter intervals for each borehole, are tabulated in Appendix II.



<u>Figure 1</u>. Location Map of the Coso Geothermal Area.

<u>Figure 2</u>. Heat Flow Borehole UTD-Coso #10. Reel, Cable, and Temperature Measuring Bridge on Ground Next to the PVC Pipe.

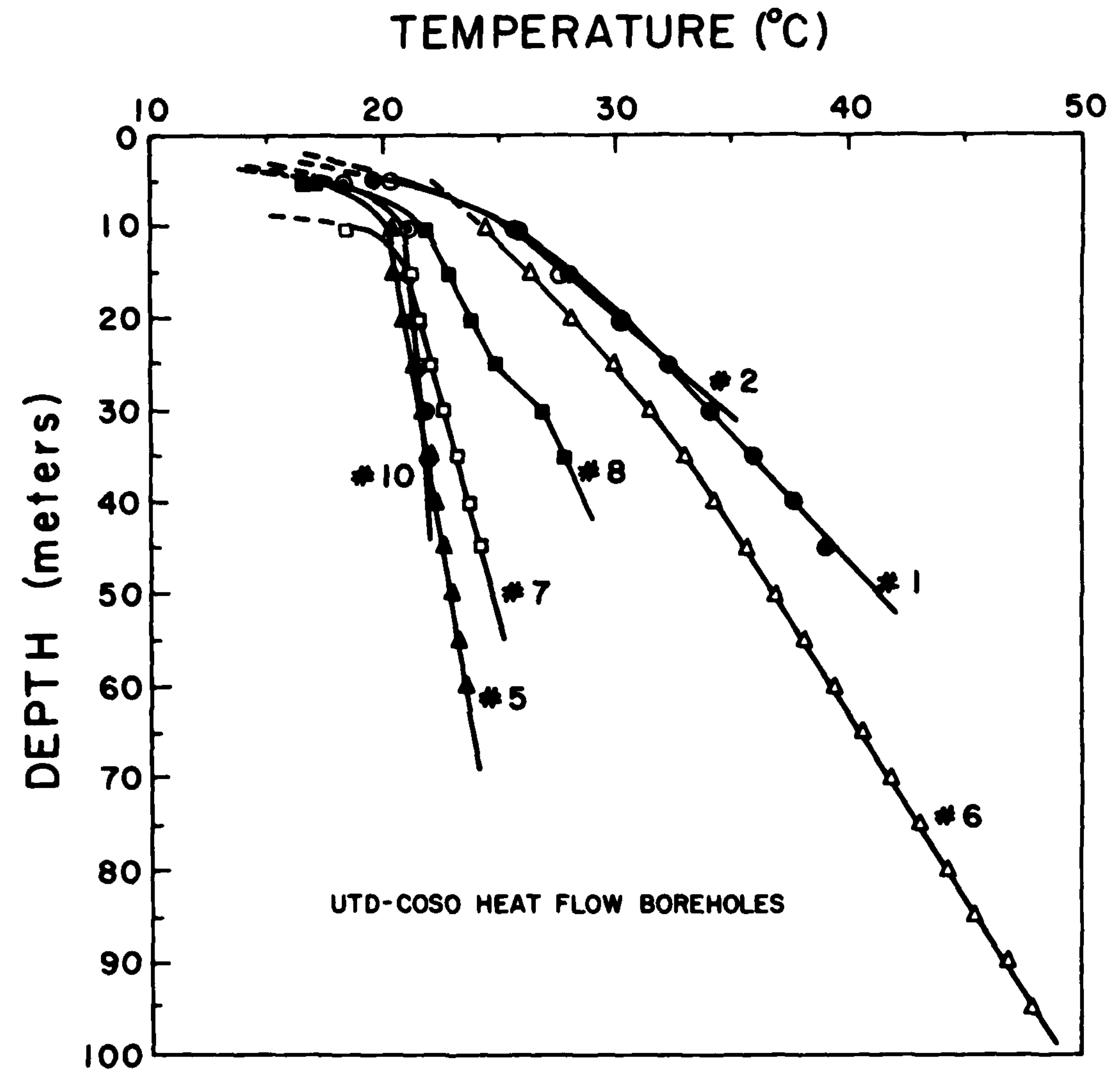


Figure 3. Temperature-Depth Curves for the UTD-Coso Heat Flow Boreholes.

As can be seen from the tables and graphs, the boreholes are quite shallow (<100 m). However, with extrapolation of the shallow gradients to ground level, an interface temperature of approximately 20°C is predicted, in good agreement with the mean annual surface temperature for the area of approximately 19°C. Because of the high geothermal gradients, surface thermal effects are rapidly overcome. The exception is UTD-Coso #10 with a gradient of 84.0 °C/km and a temperature reversal between 5 and 15 meters caused by surface thermal effects. The temperature measurements in each of the boreholes are undisturbed and indicate conductive heat transfer in the shallow subsurface.

To date, we have obtained preliminary thermal conductivity measurements in three of the boreholes using a divided bar apparatus with a cell arrangement for the drill cuttings (Sass, et al., 1971). The results of the geothermal gradient, thermal conductivity, and heat flow determinations for the borehole, UTD-Coso #6, are presented in Table 1. Note in both Figure 3 and Table 1, the surface thermal effects extend to a depth of approximately forty meters in this borehole. Below a depth of forty meters, the geothermal gradient, thermal conductivity, and therefore the heat flow values for each ten meter interval, are quite consistent. This is indicative of a steady state thermal condition in the subsurface. Heat, in the upper one hundred meters of the subsurface, is being transferred by a conductive heat transfer mechanism with an absolute value of 13 $\mu cal/cm^2$-sec (13 HFU). This heat flow value is typical of geothermal systems throughout the world (Boldizar, 1963; Dawson and Fisher, 1964; Rex, 1966; Helgeson, 1968; Horai and Uyeda, 1969; Combs, 1971) and is approximately ten times the normal terrestrial heat flow of 1.5 HFU (Lee and Uyeda, 1965; Horai and Simmons, 1969).

TABLE 1. HEAT FLOW DATA FOR UTD-COSO #6 HEAT FLOW BOREHOLE

DEPTH INTERVAL (m)	GEOTHERMAL GRADIENT (°C/km)	THERMAL CONDUCTIVITY (mcal/cm-sec-°C)	NUMBER OF SAMPLES	HEAT FLOW (mcal/cm^2-sec)
0-10	1107.0	5.2	3	58.
10-20	367.0	5.2	3	19.1
20-30	341.0	5.3	2	18.1
30-40	281.0	5.6	3	15.7
40-50	266.0	5.1	4	13.6
50-60	248.0	5.4	3	13.4
60-70	251.0	5.5	4	13.8
70-80	245.0	4.9	3	12.0
80-90	254.0	5.4	5	13.7
90-100	242.0	5.4	2	13.0

Thermal conductivity measurements have not been completed on the other boreholes; they will be obtained during the final quarter. Appropriate depth intervals, geothermal gradients, estimated thermal conductivities, and preliminary heat flow values for all of the holes, including the summary values for UTD-Coso #6, are shown in Table 2. Borehole locations and preliminary heat flow values are presented in Figure 4.

TABLE 2. COSO GEOTHERMAL AREA PRELIMINARY HEAT FLOW DATA

BOREHOLE NUMBER	ELEVATION (± 10 m)	DEPTH RANGE (m)	GEOTHERMAL GRADIENT (°C/km)	THERMAL CONDUCTIVITY (mcal/cm-sec-°C)	NUMBER SAMPLES	HEAT FLOW (μcal/cm^2-sec)
UTD-Coso #1	1134	20-40	359.2	(5)*	-	18.
UTD-Coso #2	1317	10-20	453.8	(5)	-	23.
UTD-Coso #3	1512	-	No data	-	-	-
UTD-Coso #4	1085	-	No data	-	-	-
UTD-Coso #5	1305	20-60	65.9	(5)	-	3.3
UTD-Coso #6	1268	40-95	249.3	5.3	32	13.
UTD-Coso #7	1097	20-45	101.9	(5)	-	5.1
UTD-Coso #8	1170	10-25	194.0	(5)	-	9.7
UTD-Coso #9	1542	-	No data	-	-	-
UTD-Coso #10	1170	15-35	84.0	(5)	-	4.2

* Numbers in parentheses are assumed thermal conductivity. Measured thermal conductivities will range from an approximate low of 2.5 to an approximate high of 6.5, and consequently will change the final heat flow values.

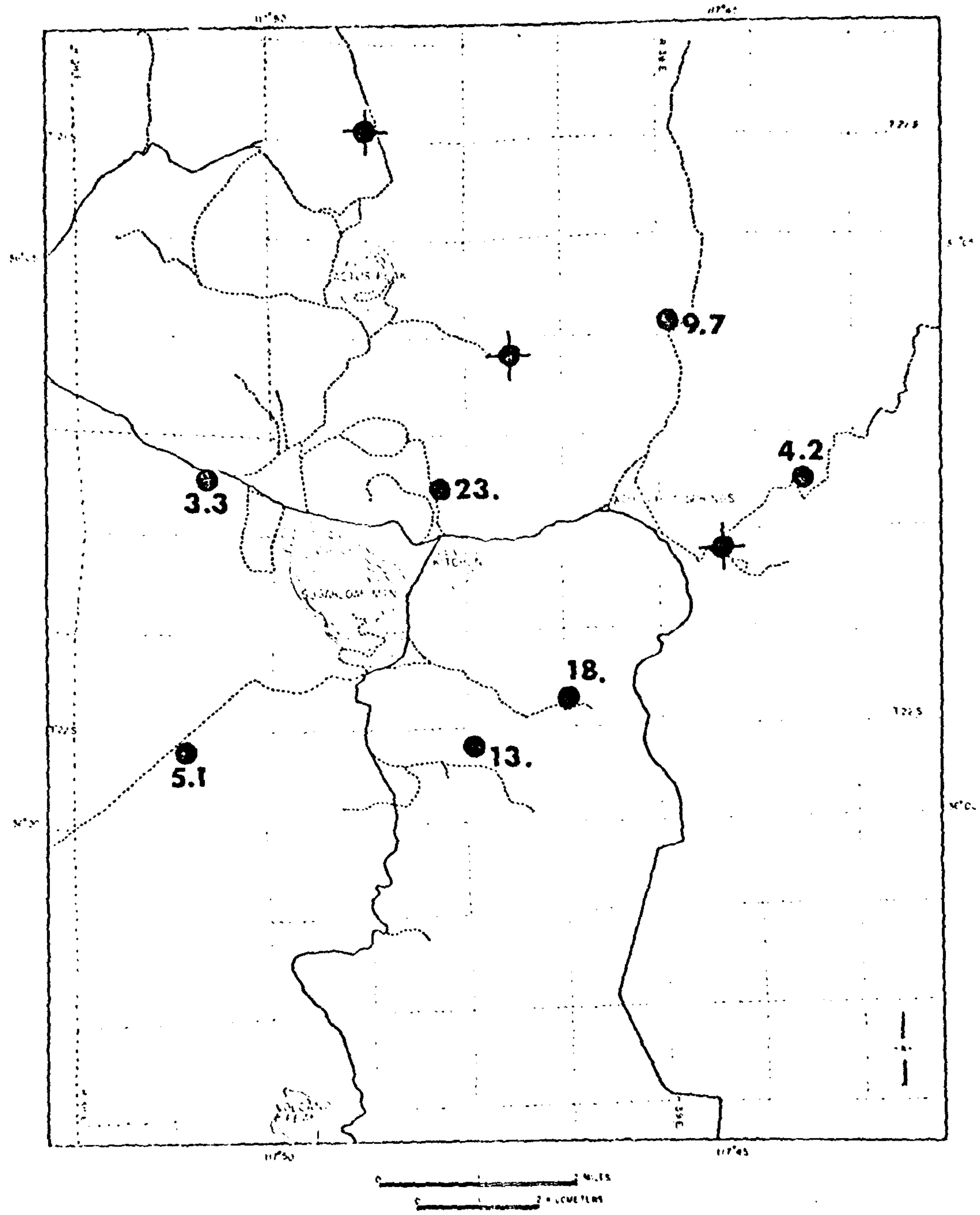


Figure 4. Base Map of the Coso Geothermal Area Showing Borehole Locations With Preliminary Heat Flow Values in Units of μcal/cm^2-sec. The Symbol ⌖ Indicates That No Data Was Obtainable From the Borehole.

Seismic Studies

During the third quarter, we continued to process, analyze, and interpret the microearthquake data. Microearthquakes clustering around the Cactus Peak area (Fig. 5) were examined in an effort to compare events arriving at the seismograph sites along different ray paths. Ray paths, between Cactus Peak and seismograph sites #3, #8, and #7, pass through an anomalously high temperature, shallow crustal zone, whereas they do not from Cactus Peak to site #5.

Since P- and S- residuals from well located microearthquakes usually range from -0.02 to 0.02 seconds, anomalous ones are easy to pick. At seismograph station #7, the P-arrivals for eight events studied arrived slightly early, while the S phase was quite late. Site #7 is at least ten kilometers from the hypocentral region for the Cactus Peak events. Ray paths may pass through regions with quite different ratios of V_P to V_S which would explain the P-and S-residuals.

The S phases are attenuated at sites #3, #8, and #7 indicating the elastic waves have passed through a high temperature, shallow crustal zone. Similar phenomena are not apparent on records obtained at seismograph site #5. These anomalous seismic phenomena substantiate the high heat flow data obtained in this preliminary analysis.

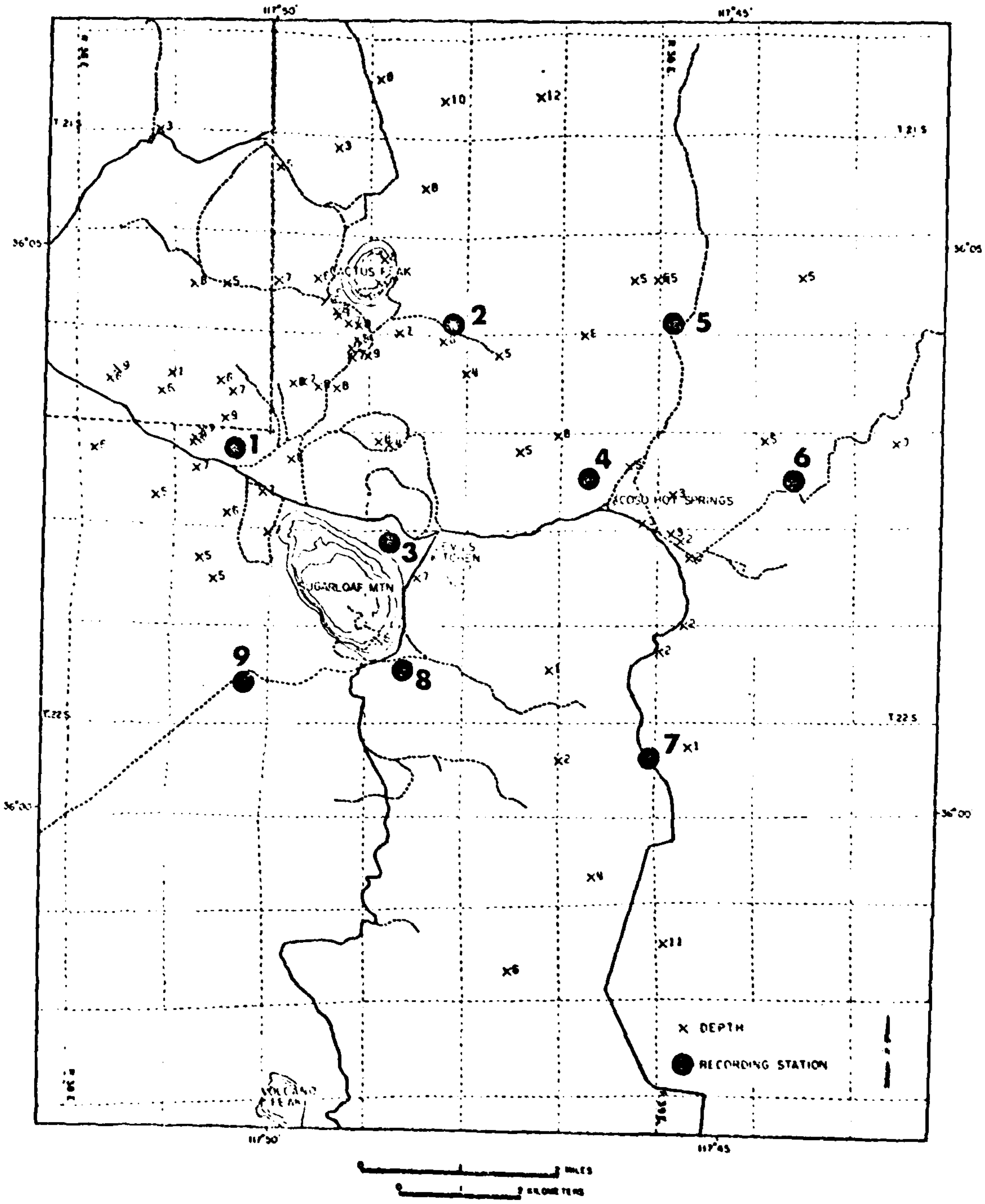


Figure 5. Base Map of the Coso Geothermal Area Showing Location of the Nine Seismograph Sites and Epicenters for 78 Microearthquakes. The Number Beside Each Epicenter Denotes the Focal Depth in Kilometers.

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APPENDIX I

Temperature-depth curves for the seven heat flow boreholes that were deep enough to provide a reasonable estimate of the geothermal gradient are presented in Figures I-1 through I-7. After the drilling and coring were completed, PVC pipe with a closure on both ends was lowered into the holes. Drill cuttings were caved around the pipe. The pipe was then filled with water in order to provide for thermal stability during future temperature measurements. All of the boreholes were completed above the local water table. Temperatures as a function of depth for each borehole are tabulated in Appendix II.

The temperature measurements in each of the boreholes are undisturbed and indicate conductive heat transfer in the shallow subsurface. Because of the high geothermal gradients, surface thermal effects are rapidly overcome. The one exception is the UTD-Coso #10 borehole with a gradient of 84°C/km and a temperature reversal between 5 and 15 meters caused by surface thermal effects. The boreholes are quite shallow (<100 m). However, with extrapolation of the shallow gradients to the surface, a surface temperature of approximately 20°C is predicted in good agreement with the mean annual surface temperature of approximately 19°C for the area.

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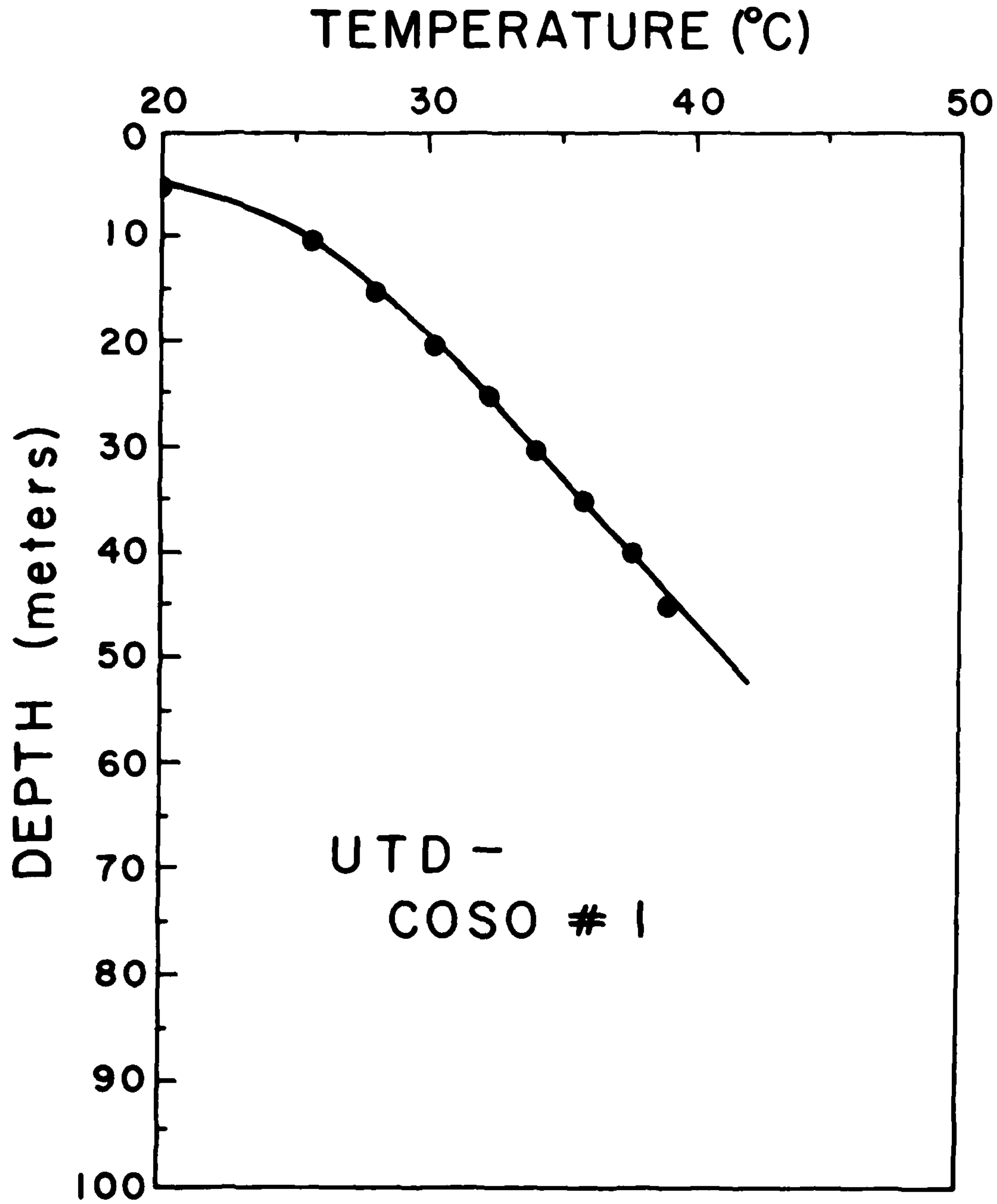


Figure I-1. Temperature-Depth Curve for Borehole UTD-Coso #1.

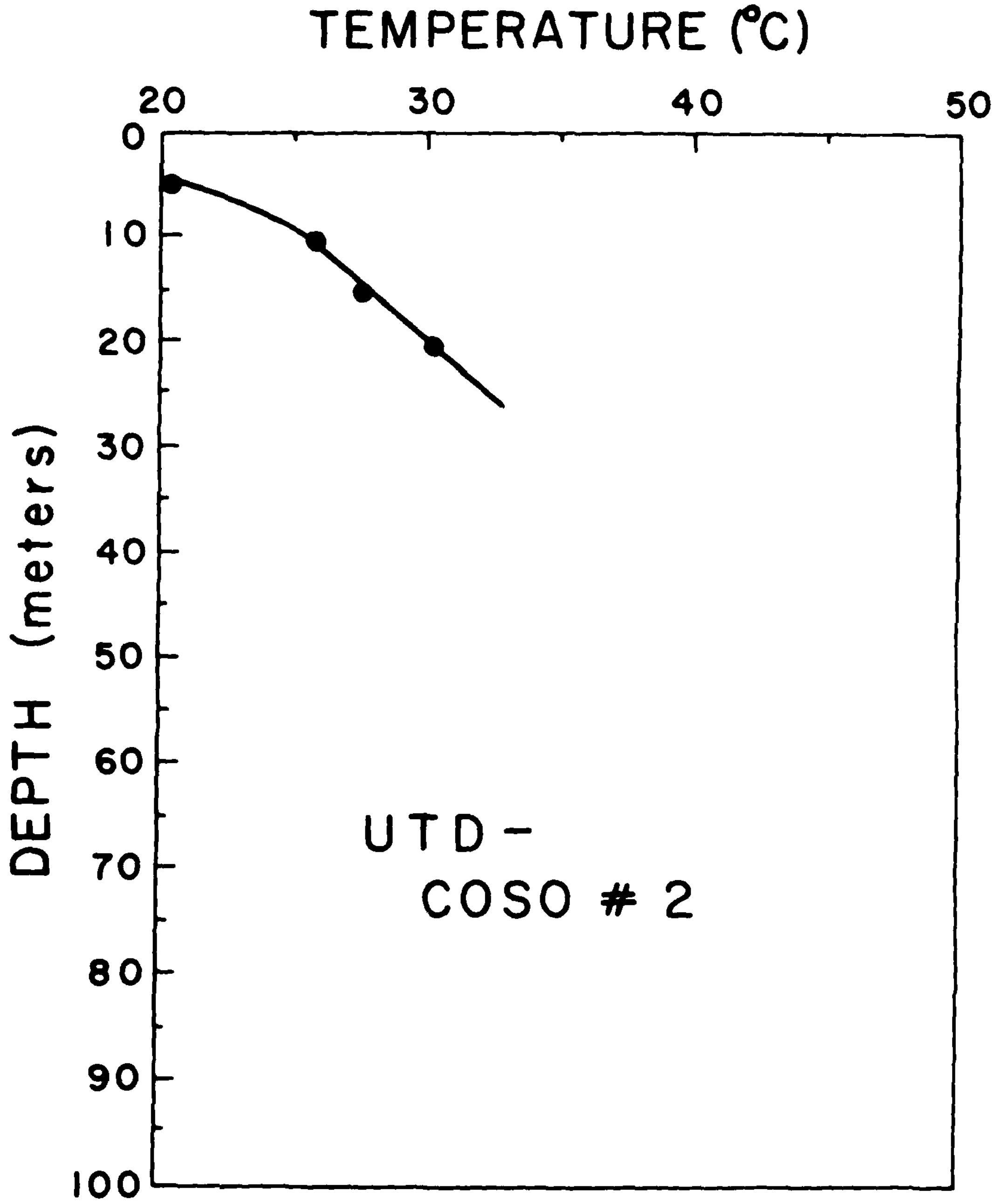


Figure I-2. Temperature-Depth Curve for Borehole UTD-Coso #2.

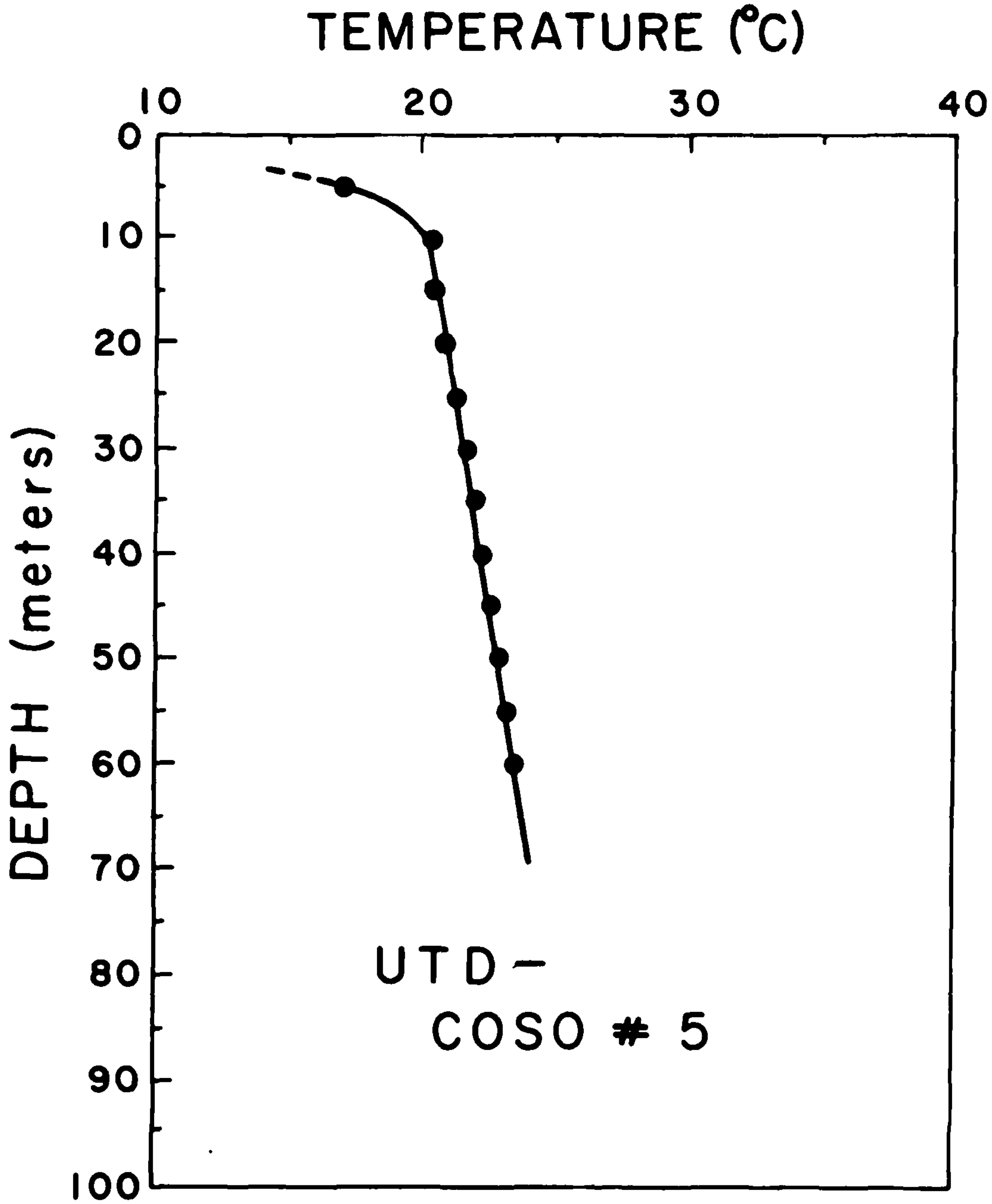


Figure I-3. Temperature-Depth Curve for Borehole UTD-Coso #5.

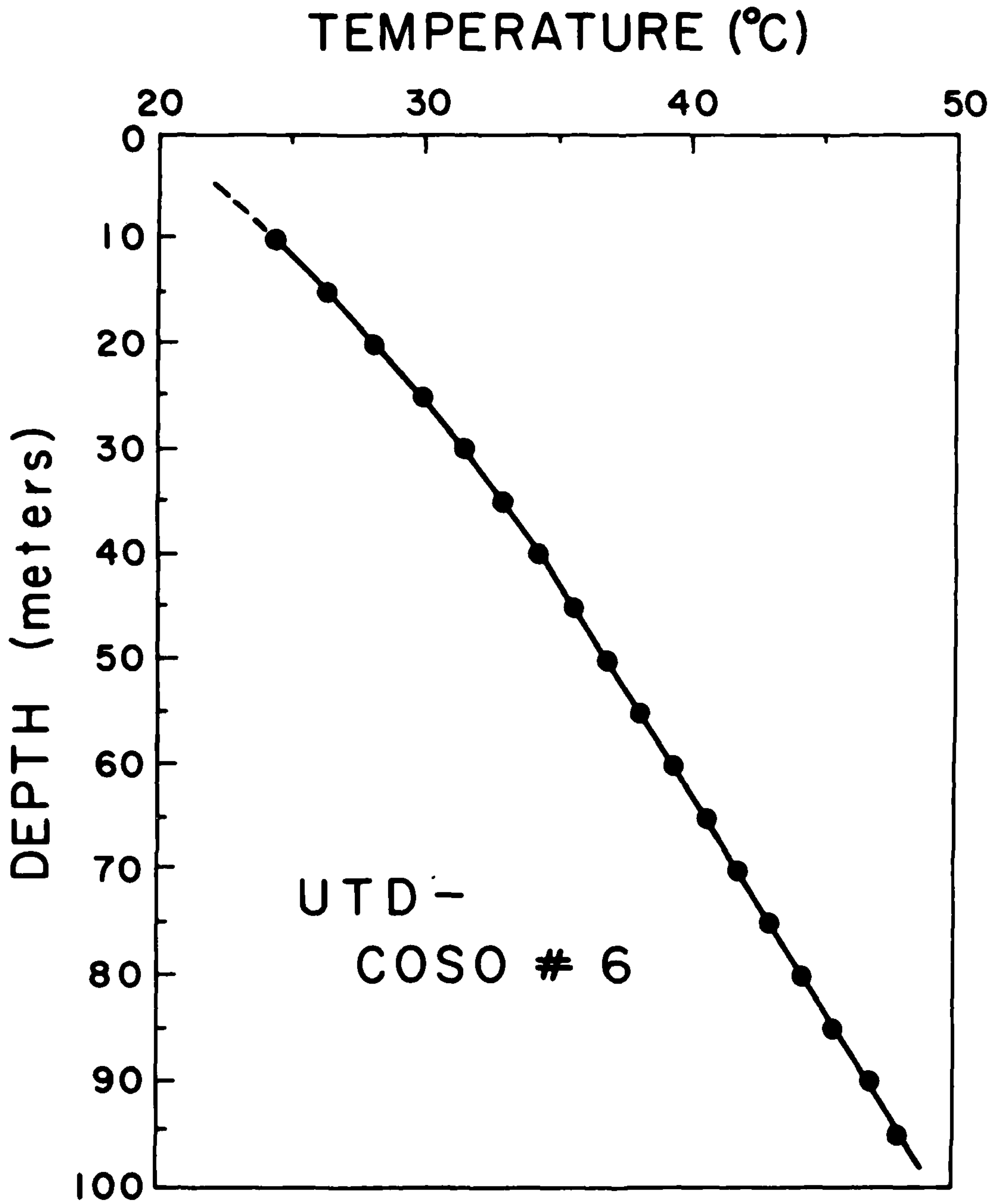
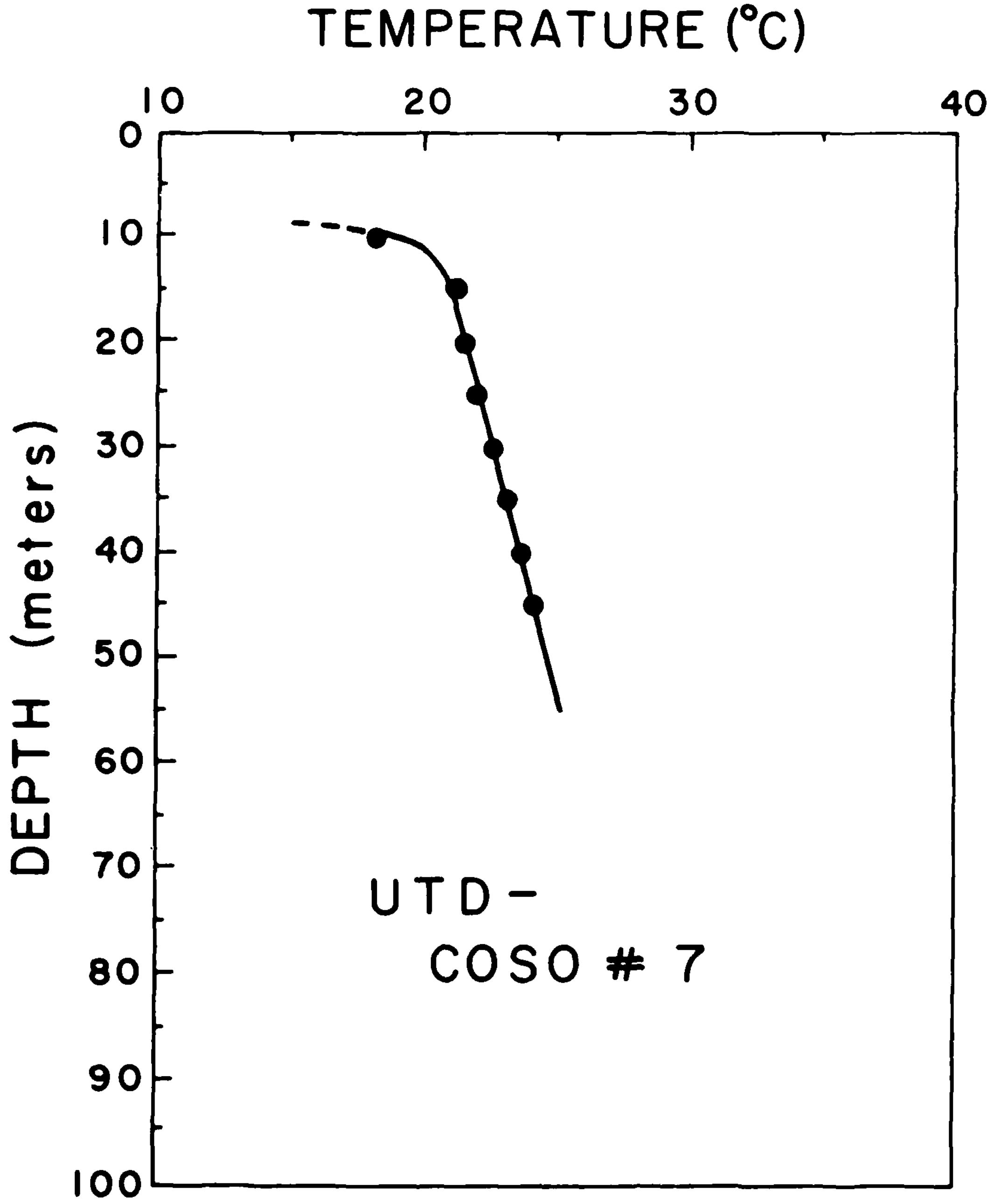
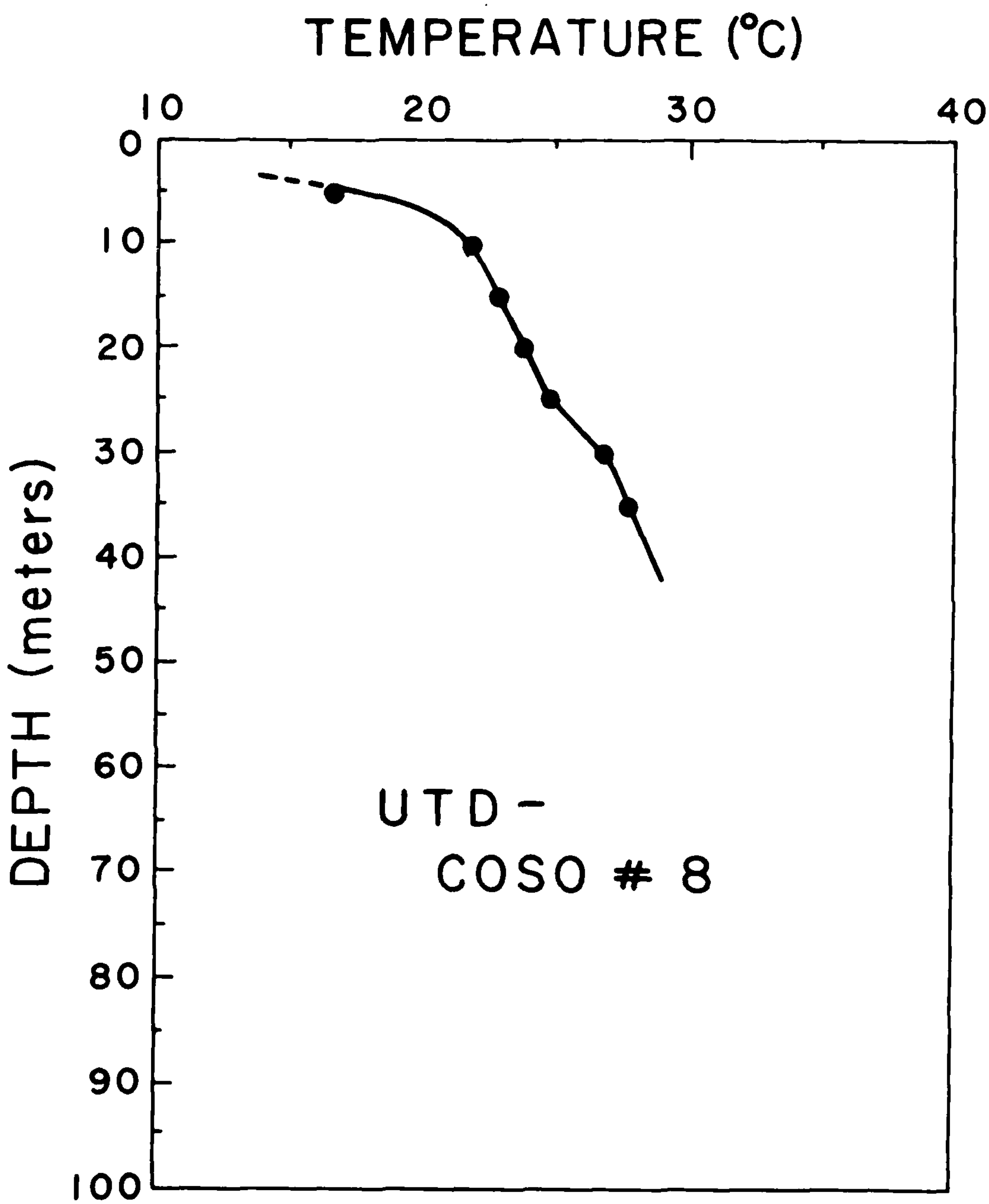


Figure I-4. Temperature-Depth Curve for Borehole UTD-Coso #6.



<u>Figure I-5</u>. Temperature-Depth Curve for Borehole UTD-Coso #7.



<u>Figure I-6</u>. Temperature-Depth Curve for Borehole UTD-Coso #8.

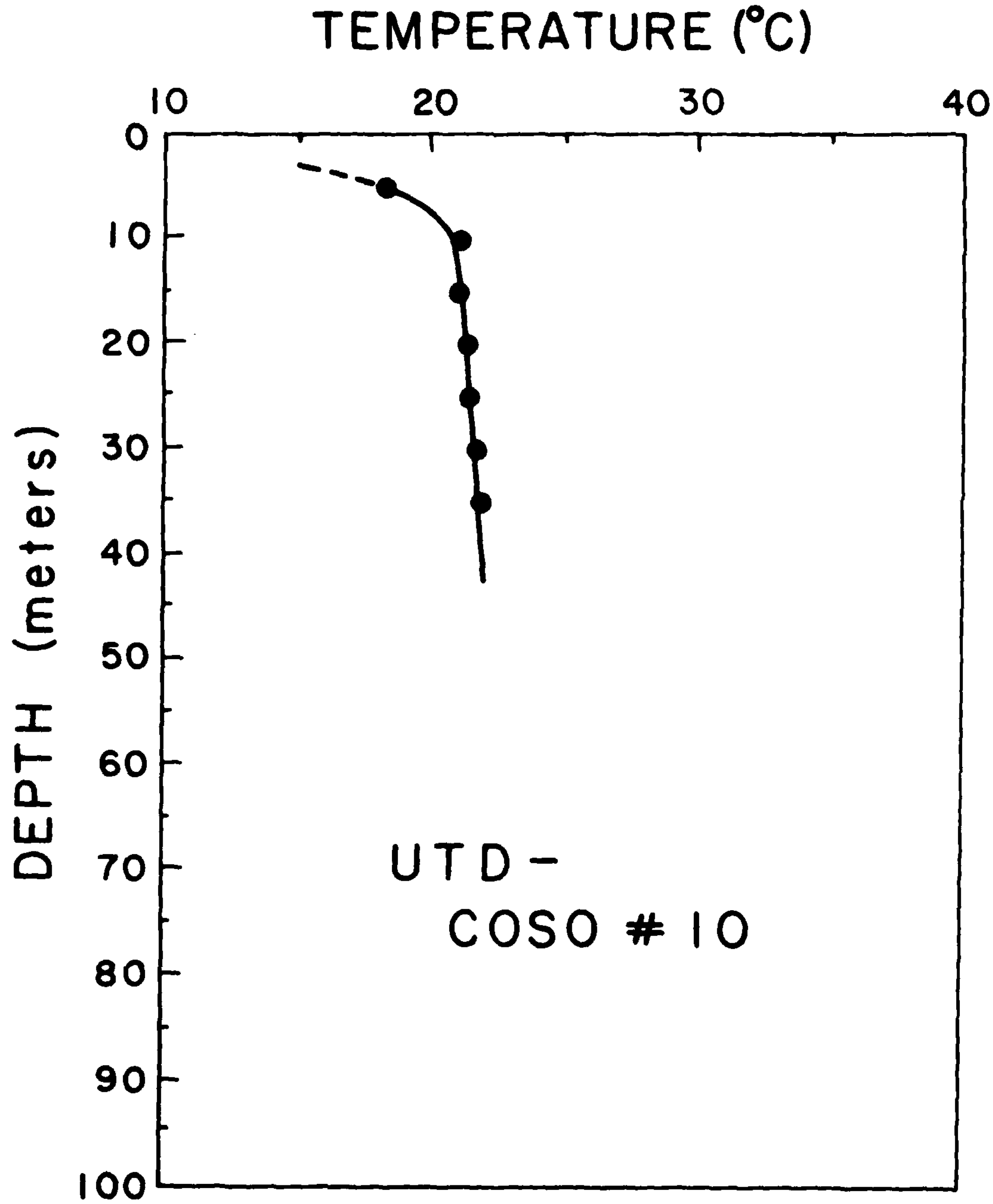


Figure I-7. Temperature-Depth Curve for Borehole UTD-Coso #10.

APPENDIX II

Temperature Measurements

In this appendix DEPTH refers to the depth in meters below ground level and TEMPERATURE is the temperature at the indicated depth in degrees Celsius.

UTD - Coso #1

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	11.12
5	19.61
10	25.60
15	27.96
20	30.21
25	32.22
30	34.03
35	35.82
40	37.62
45	38.94

UTD - Coso #2

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	9.70
5	20.29
10	25.75
15	27.56
20	30.30

UTD - Coso #3

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	7.47
5	12.29
10	15.89
15	15.77

UTD - Coso #4

Borehole too shallow for temperature measurements.
No data.

UTD - Coso #5

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	9.51
5	17.06
10	20.35
15	20.46
20	20.85
25	21.27
30	21.67
35	22.02
40	22.34
45	22.66
50	22.98
55	23.30
60	23.59

UTD - Coso #6

Temperatures measured: 2/10/75

DEPTH	TEMPERATURE
0	13.44
5	20.47
10	24.51
15	26.37
20	28.18
25	30.01
30	31.59
35	33.12
40	34.40
45	35.73
50	37.06
55	38.30
60	39.54
65	40.83
70	42.05
75	43.29
80	44.50
85	45.72
90	47.04
95	48.14

UTD - Coso #7

Temperatures measured: 2/10/75

DEPTH	TEMPERATURE
0	15.57
5	17.23
10	21.18
15	21.23
20	21.54
25	21.97
30	22.50
35	23.07
40	23.58
45	24.04
50	24.42

UTD - Coso #8

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	9.68
5	16.61
10	21.84
15	22.90
20	23.79
25	24.81
30	25.81
35	26.68

UTD - Coso #9

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	9.58
5	14.96
10	17.20

UTD - Coso #10

Temperatures measured: 2/11/75

DEPTH	TEMPERATURE
0	11.94
5	18.21
10	21.06
15	21.04
20	21.26
25	21.46
30	21.69
35	21.89